PRE-STRESS TECHNIQUE FOR THE FLEXURAL STRENGTHENING WITH NSM-CFRP STRIPS

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1 INTRODUCTION

The effectiveness of the Near Surface Mounted (NSM) strengthening technique to increase the flexural resistance of reinforced concrete (RC) beams [1, 2] and slabs [3] was already well assessed. In fact, passive (without any pre-stress level) CFRP strips, installed into thin slits opened onto the concrete cover subjected to tension, and bonded to the concrete substrate with an adhesive, can increase significantly the load carrying capacity of RC elements, mainly when the percentage of existing steel reinforcement is relatively low. However, for deflection levels corresponding to the serviceability limit states, the increase of the load carrying capacity of these structures, provided by this strengthening technique, can be of reduced amplitude. To obtain a significant increment in terms of load carrying capacity for these deflection levels, the strips should be applied with a certain pre-stress level, but, in general, relatively sophisticated devices are being proposed [4, 5]. In the present work, a new strengthening technique of relatively simple execution, based on applying NSM CFRP strips with a certain pre-stress level, was developed and its effectiveness was appraised by an exploratory experimental program.

2 PRE-STRESS TECHNIQUE CONCEPT

Figure 1 schematically describes the concept subjacent to the technique for applying CFRP strips with a certain pre-stress level for the flexural strengthening of RC beams. Near the zones where the strips will be anchored, the concrete cover is removed (Fig. 1a) for the installation of a steel piece that includes a pair of clamping wedges to fix the extremities of the strip (Figs. 1c and 1d). In the concrete cover of the beam, slits are opened for the installation of the strips (Fig. 1b). To avoid premature concrete splitting failure mode when the pre-stress in the strip is transferred to the surrounding concrete, the slit should have a non-constant width, since, due to the relatively low elasticity modulus of the adhesives used to bond CFRP strips to concrete, the adhesive elastic deformability assures a smooth stress transfer from strip to concrete. A pair of braces is used to keep temporarily the anchoring system in place (Fig. 1e). The system to apply the pre-stress to the strips is composed of an actuator and tubular steel profiles (Figs. 1f and 1g). These steel profiles have the purpose of transfer the load from the actuator to the anchorage steel pieces, and finally, to the strips. Due to the action-reaction principle, the element that supports the actuator transfers the load to the supporting pavement. Since CFRP strips can include optical fiber sensors, the applied stress level can be correctly controlled. After the aimed stress level having been applied to the strip, the load should smoothly decrease in order to avoid the occurrence of high stress gradients during the stress transfer process from strip to the surround medium.

3 SERIES OF BEAMS

The preliminary experimental program is composed by three RC beams. The beams have a cross-section of 120 mm width and 200 mm depth, and the bottom longitudinal steel bars have a concrete cover of 25 mm thickness. The V00 reference beam has 2Φ12 steel bars, both in bottom and top surfaces, and Φ8//100mm steel stirrups. VLP and VRC20 beams, besides these steel reinforcements, they were also strengthened with a CFRP strip of 10×1.2 mm^2 cross section, placed at the middle of the tensile bottom surface of the beams. In VLP beam the strip was applied without any pre-stress level (passive strip), while in VRC20 beam a pre-stress level of 20% of the tensile strength of the strip was applied (500 MPa of pre-stress).

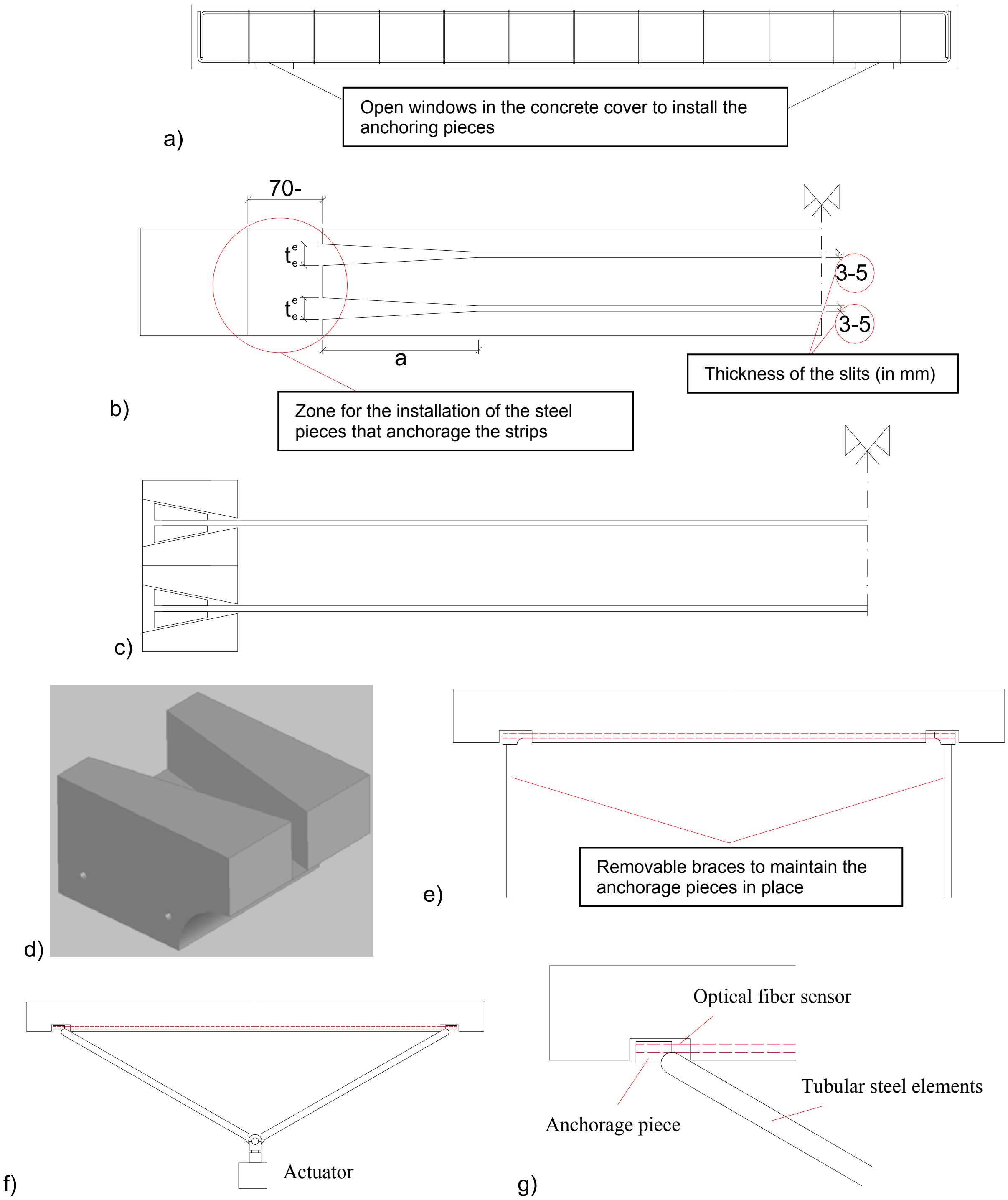

Fig. 1 Pre-stress technique for NSM CFRP strips.

4 PROPERTIES OF THE INTERVINING MATERIALS

From compression tests with 8 cubic specimens of 150 mm edge, an average compressive strength of 37.5 MPa, with a standard deviation of 7.2 MPa, at 28 days, was obtained for the concrete of the beams. Steel bars of corrugated surface and with a characteristic yield stress of 500 MPa were used. After having been done a thorough search on the market for an adhesive of fast curing, the “concresive 400” adhesive from BASF was selected, since amongst the candidates adhesives was the one with the lowest curing time, and demonstrated to have adequate characteristics to bond CFRP strips to concrete. To evaluate the tensile strength, f_{fa}, and the secant elasticity modulus, E_a, of this adhesive, 5 specimens were tested. These specimens have a thickness of 4 mm, which is similar to the thickness of the adhesive layer after fixing the CFRP strip into the slit. In the present preliminary

experimental program, slits of approximately constant width of 10 mm were executed. To assess the curing time effect on the f_{fa} and E_a, tests were carried out with specimens of 2, 4, 5, 6 and 24 hours of curing. The obtained results are included in Table 1, from whose it can be concluded that after 4 hours of curing the adhesive presented a tensile strength and an elasticity modulus of about, respectively, 95% and 87% of the corresponding values measured at 24 hours of curing, a period of time that seems to be sufficient to attain the plenitude of the adhesive properties.
According to the supplier (S&P), the CFRP strips, of a 10×1.4 mm^2 cross section area, have an elasticity modulus of 160 GPa and a tensile strength higher than 2500 MPa.

Table 1 Results of the tensile tests with adhesive specimens.

Specimen	Curing time, T_c [hours]	f_{fa} [MPa]	E_a [GPa]
PR2	2	18.407	1.708
PR4	4	21.330	2.422
PR5	5	20.921	2.987
PR6	6	21.420	2.407
PR24	24	22.400	2.776

5 TEST SETUP

The beams, with 2.0 m length and 1.8 m between the supports, were subjected to four point loads, according to the scheme represented in Fig. 2. The distance between the internal applied point loads is 0.6 m, resulting a shear span ratio, *a/d*, of 3.7 (*a* is de distance between the applied point load and its nearest reaction support, while *d* in the effective depth of the beam cross section), a test configuration to promote the occurrence of flexural failure mode. To measure the beam deformability, four displacement transducers (LVDTs) were placed according to the scheme represented in Fig. 3, while strain gauges, installed in the strip according to this scheme, were used to measure the evolution of the strains during the loading process. Optical fiber sensors were also used, but they were damaged during the application process of the pre-stress.

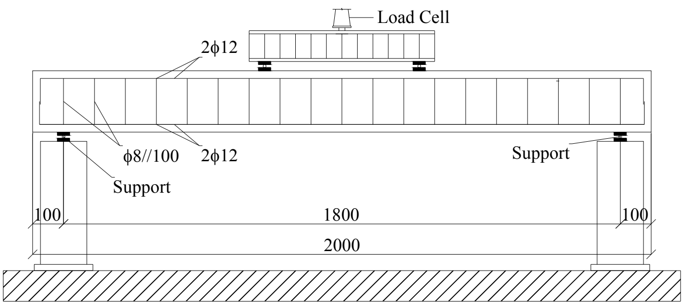

Fig. 2 Test setup (dimensions in mm).

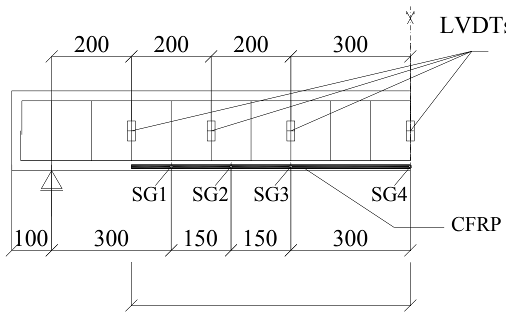

Fig. 3 Position of the LVDTs and strain gauges (dimensions in mm).

5 RESULTS AND ANALYSIS

Fig. 4 represents the relationship between the midspan deflection, δ, and the total applied load of the tested beams, while Fig. 5 shows the relationship between δ and $\left(F_{\max}^{\mathrm{Str}} - F_{\max}^{\mathrm{V00}}\right)/F_{\max}^{\mathrm{V00}}$, where $F_{\max}^{\mathrm{Str}}$ and $F_{\max}^{\mathrm{V00}}$ are the maximum load of the strengthened and reference beams, respectively. The main results are included in Table 2 (F_{cr}^{Str}, F_{cr}^{V00}: cracking load of the strengthened and reference beams; $\delta_{\mathrm{Fmax}}^{\mathrm{Str}}$, $\delta_{\mathrm{Fmax}}^{\mathrm{V00}}$: midspan deflection at the maximum load of the strengthened and reference beams).

Table 2 Main obtained results.

Beam	F_{cr} (kN)	$\frac{F_{cr}^{\mathrm{Str}} - F_{\mathrm{cr}}^{\mathrm{V00}}}{F_{\mathrm{cr}}^{\mathrm{V00}}}\times 100$	$F_{\max}$ (kN)	$\frac{F_{\max}^{\mathrm{Str}} - F_{\max}^{\mathrm{V00}}}{F_{\max}^{\mathrm{V00}}}\times 100$	δ^{Fmax} (mm)	$\frac{\delta_{\mathrm{Fmax}}^{\mathrm{Str}} - \delta_{\mathrm{Fmax}}^{\mathrm{V00}}}{\delta_{\mathrm{Fmax}}^{\mathrm{V00}}}\times 100$
V00	10.07	-	54.72	-	30.475	-
VLP	11.50	14.2	76.72	40.2	19.859	-34.8
VRC20	13.72	36.2	81.80	49.5	28.804	-5.5

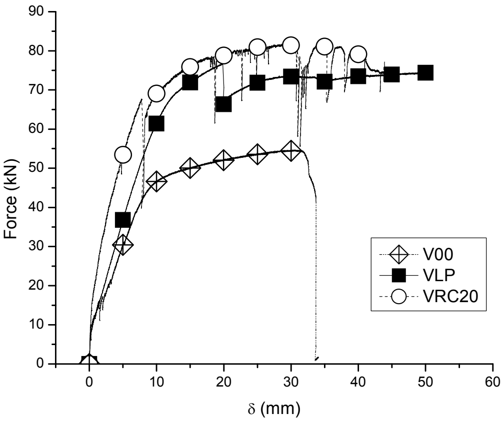

Fig. 4 Midspan deflection *vs* applied total load.

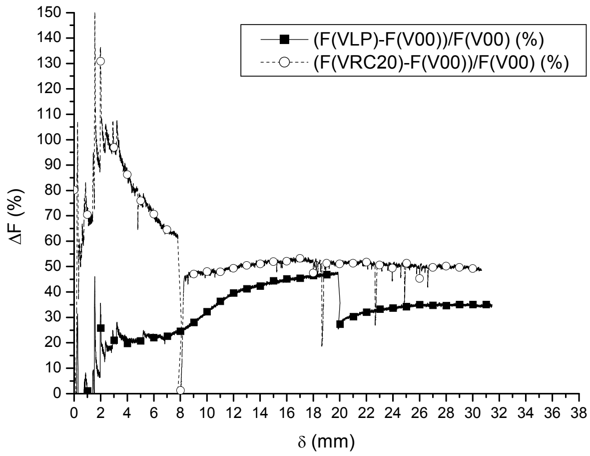

Fig. 5 Load increment provided by the strengthening systems.

6 CONCLUSIONS

From the obtained results it can be concluded that a pre-stress level of 20% of the CFRP strip tensile strength provided an increment in terms of cracking load and maximum load of about 36% and 50%, respectively (taking the corresponding values of the V00 reference beam). If comparison is restricted to the maximum load of the VLP beam (strengthened with a passive strip), the pre-stress level only provided an increase of about 10%. However, as Fig. 5 shows, the increment of load carrying capacity up to a midspan deflection corresponding to the verification of the serviceability limit states, SLS, (L/400=4.5 mm), provided by 20% pre-stress level, exceeded 100% in VRC20, while in VLP beam was limited to 25%. It is also notable that, for a deflection almost the double the corresponding deflection for SLS, the load increment provided by the pre-stress technique was about 60%, while in the VLP beam this increase was 25%. In conclusion, the proposed technique seems to be very effective, and a much larger experimental program is being prepared in order to assess the influence of relevant aspects on the effectiveness of this technique.

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